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QoT AWARE LOAD BALANCING ROUTING IN MANET USING RELAY TYPE OF AMPLIFY AND FORWARD BASED COOPERATIVE COMMUNICATIONS*

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Abstract. In research topics to improve the performance of the mobile ad hoc networks (MANET), the load balancing routing has attracted many research groups because it is an effective solution to reduce traffic congestion. However, to balance the traffic load, the routing algorithm often has to choose some long routes. These routes pass through many hops and intermediate nodes, so the accumulated noise along with the route increases. As a result, the quality of transmission (QoT) of data transmission routes decreases, especially in the case of MANET using the relay type of amplify-and-forward (AF), where the noise power can be amplified at intermediate nodes. Therefore, it is necessary to study the QoT aware load balancing routing algorithms. In this paper, we focus on investigating the QoT in the MANET using AF and propose a load balancing routing algorithm under the constraint of the QoT. The proposed algorithm is improved from the new route discovery algorithm of the on-demand routing protocol. Our idea is to combine the operation of the route request and reply packets to collect the information of the traffic load and QoT from source to destination, used for the objective and the constraints of selecting a new route. Our evaluation by simulation method has shown that the proposed algorithm can improve the network performance in terms of the QoT, packet loss probability, and network throughput compared with the original routing algorithms.

Keywords. MANET using AF; QoT aware routing; Load balancing routing.

1. INTRODUCTION

The demand for wireless networking systems is growing, especially in the era of the internet of things (IoT) and the fourth industrial revolution. Among the multi-hop wireless network models, the mobile ad hoc network (MANET) is becoming more and more widely used in many fields, such as community network, enterprise network, home network, emergency response network, vehicle network and sensor network [1]. The basic characteristic of MANET is that the network topology frequently changes according to the random movement of the nodes. Therefore, the routing table at each node is also updated periodically to ensure the freshness of the data transmission routes [2].

Recently, the research topics on the architecture and control protocol of MANET have attracted many research groups. The objective of these works is to improve the performance of MANET. For the architecture, several published works have focused on the cross-layer model [2–4], software-defined networking architecture [5–8]. For the control protocols, some

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research groups have also been interested in the optimal routing protocols such as the QoT aware routing [9–12], the load balancing routing [13–16], the security-aware routing [17, 18]. Among the optimal routing protocols, the load balancing routing is the most effective solution to improve the MANET performance in terms of the packet loss probability, packet delivery ratio, and network throughput. However, due to the essential characteristics of this routing is that the data transmission routes can pass through many intermediate nodes, this may increase the accumulated noise along the route. As a result, the QoT of the data transmission channels in the network decreases, especially in the case of MANET using the AF relay type based cooperative communications, where the power of the noise signal can amplify at intermediate nodes. Therefore, it is necessary to study load balancing routing algorithms taking into account QoT in the MANET using the AF relay type. This is the research motivation of this paper. We investigate the QoT on the data transmission routes in the MANET using AF. Then, a QoT aware load balancing routing algorithm is proposed to improve the network performance.

The next sections of the paper are organized as follows. Section 2 focuses on analyzing the QoT of the data transmission routes in MANET using the AF type relay. Section 3 presents our proposed routing algorithm. The simulation results and discussions are presented in Section 4. Finally, conclusions and future works are presented in Section 5.

2. QoT OF DATA TRANSMISSION ROUTES IN MANET USING RELAY TYPE OF AMPLIFY AND FORWARD

We first list the important notations used for the remainder of this paper, described as in Tab. 1.

Table 1. The symbols and notations are used in the paper

Notation	Description
$h_{i,j}$	Hop from node i to node j.
$r_{s,d,k}$	Route k from node s to node d.
$\beta_{h_{i,j}}$	Signal-to-noise ratio (SNR) of the hop from node i to node j.
$\beta_{r_{s,d,k}}$	SNR of the route k from node s to node d.
β_{req}	Required SNR for ensuring QoT in the network.
$\beta_{r_{s,d}}$	SNR of the route from node s to node d that is chosen by QALR algorithm ($\beta_{r_{s,d}} \geq \beta_{req}$).
$L_{r_{s,d}}^{(max)}$	The maximum traffic load of the links in route from node s to node d.
$L_{h_{i,j}}$	The traffic load of the hop from node i to node j.

According to the principle of multi-hops communication technology in wireless networks, the signal to noise (SNR) at the destination node of a route depends on the relay type at intermediate nodes, which is amplify-and-forward (AF) or decode-and-forward (DF) [19, 20]. The AF relay type is often used for some ad hoc network models [21–23]. For this relay type, the SNR at the destination node of a route is determined by

$$\beta_{r_{s,d,k}} = \left(\sum_{h_{i,j} \in r_{s,d,k}} \frac{1}{\beta_{h_{i,j}}} \right)^{-1}. \tag{1}$$

Equation (1) shows that the SNR of a route decreases according to the number of hops along to that route. To see clearly this comment, we consider an example as shown in Figure 1. There are two possible routes from S to D, $r_{s,d,1}$ and $r_{s,d,2}$ along the nodes of S $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D and S $\rightarrow$ A $\rightarrow$ E $\rightarrow$ F $\rightarrow$ D, respectively. According to (1), if the route $r_{s,d,1}$ is used, the SNR at the destination node (D) is 24.2dB. This value is 23.1dB in case of the route $r_{s,d,2}$. Assuming the 256-QAM modulation format is used, the required quality of service (QoS) of the network system is the maximum bit error ratio (BER) of 10^{-6}. Based on the relationship between SNR and BER determined according to the theory of modulation formats [24], to be able to obtain the maximum BER of 10^{-6}, the SNR must be at least 23.5 dB [13]. For two routes of $r_{s,d,1}$ and $r_{s,d,2}$ above, the route of $r_{s,d,2}$ does not guarantee the QoT because its SNR is less than the minimum required SNR (23.5dB). Meanwhile, this route can still be used for transmitting the data packets if the load balancing routing algorithms are used in the network. Thus, it is essential to consider the constraint of the QoT in the load balancing routing algorithms, especially in case of the MANET using AF relay type. This issue has been investigated in our proposed routing algorithm, presented in detail in the next section.

Hop	SNR (dB)
S → A	29
A → E	31
E → F	29
F → D	28
S → B	28
B → C	30
C → D	29

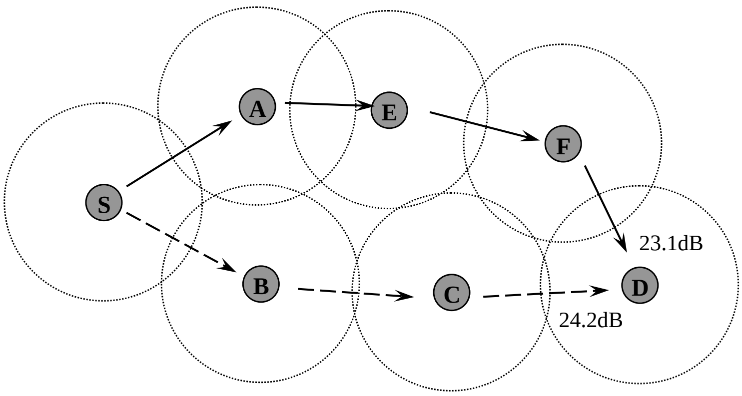

Figure 1. An example of the SNR of the routes in MANET using AF relay type

3. QUALITY OF TRANSMISSION AWARE LOAD BALANCING ROUTING ALGORITHM

In this section, we present the load balancing that takes account the QoT of the data transmission routes, proposed for MANET using the AF relay type based cooperative communications. The proposed algorithm is called Quality of transmission Aware Load balancing Routing (QALR), improved from the route discovery algorithm of the dynamic source routing protocol (DSR) in MANET [25]. The QALR algorithm aims to find the route set to transmit data so that the traffic load is uniformly distributed across all connections. This route set satisfies the QoT constraints concurrently.

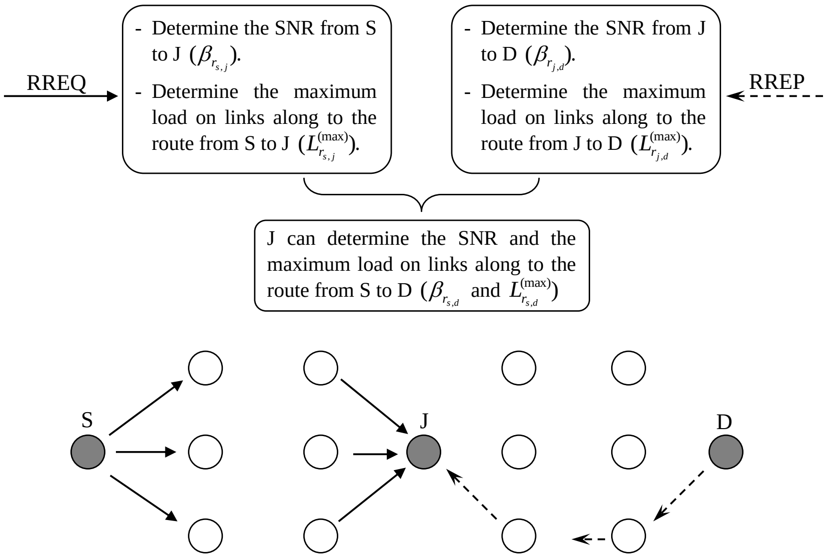

Figure 2. The model illustrates for the ieda of the QALR algorithm

Figure 2 illustrates the idea of the proposed QALR algorithm, where we modify the operation principle of the route request packet (RREQ) and the route reply packet (RREP) to determine the maximum traffic load of the links ($L^{(max)}_{r_{s,d}}$) and SNR ($\beta_{r_{s,d}}$) along the route from the source node to destination node. $L^{(max)}_{r_{s,d}}$ and $\beta_{r_{s,d}}$ are used for the objective of

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Algorithm 1: QALR algorithm at source node (S)

Node S creates the RREQ packet;
`// Initialize the values SNR and maximum load, stored into RREQ;`
$L^{(max)}_{r_{s,s}} \leftarrow 0$;
$\beta_{r_{s,s}} \leftarrow$ 0xFFFF; `// A value big enough;`
Store $L^{(max)}_{r_{s,s}}$ and $\beta_{r_{s,s}}$ into the RREQ;
S broadcasts RREQ to all its neighbours;
while ($T_{wait} < T_{lim}$) **do** `//` T_{lim} `is limit time for discovering new route;`
  if (*RREP packet arrives node S*) **then**
    if (*S has not received any RREP packet before*) **then**
      Update the new route into the route cache of S;
    else
      if ($L^{(max)}_{r_{s,d}}$ *in route cache of* $S > L^{(max)}_{r_{s,d}}$ *in RREP*) **then**
        Update the new route into the route cache of S;
      end
    end
    delete RREP packet;
  end
end

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choosing the load balancing route and the constraint of QoT, respectively.

Because QALR is a distributed routing algorithm, the intermediate nodes do not know the full information of nodes that are not its neighbours by default. Thus, we modify the working principle of the RREQ and RREP so that an intermediate node can know the full information of $L^{(max)}_{r_{s,d}}$ and $\beta_{r_{s,d}}$ from the source node to destination node. Considering an intermediate node J, when J receives a RREQ packet from neighbor node I, based on the information of $L^{(max)}_{r_{s,i}}$ and $\beta_{r_{s,i}}$ is stored in RREQ and the information of $L_{h_{i,j}}$ and $\beta_{h_{i,j}}$, node J determines the maximum traffic load of the links ($L^{(max)}_{r_{s,j}}$) and SNR ($\beta_{r_{s,j}}$) from

Algorithm 2: QALR algorithm at the intermediate node (J)

Node J receives a control packet from its neighbour node (I);
if (*Received control packet is RREQ*) **then**
    Read the values $L^{(max)}_{r_{s,i}}$ and $\beta_{r_{s,i}}$ in RREQ;
    Determine the values $L_{h_{i,j}}$ and $\beta_{h_{i,j}}$;
    $L^{(max)}_{r_{s,j}} \leftarrow Max(L^{(max)}_{r_{s,i}}, L_{h_{i,j}})$;
    $\beta_{r_{s,j}} \leftarrow 1/(1/\beta_{r_{s,i}} + 1/\beta_{h_{i,j}})$;
    Add a record of the reverse route to S with the format $\{I, L^{(max)}_{r_{s,j}}, \beta_{r_{s,j}}\}$ into route cache of J;
    if (*J already received this RREQ*) **then**
        Discard RREQ;
    else
        Broadcast RREQ to all neighbours of J;
    end
else
    `// Received control packet is RREP`
    Read the values $L^{(max)}_{r_{j,d}}$ and $\beta_{r_{j,d}}$ in RREP;
    $L^{(min)}_{r_{s,j}} \leftarrow$ 0xFFFF; `// A value big enough`
    for (*each record* $\{I, L^{(max)}_{r_{s,j}}, \beta_{r_{s,j}}\}$ *stored in route cache of J*) **do**
        $\beta_{r_{s,d}} \leftarrow 1/(1/\beta_{r_{s,j}} + 1/\beta_{r_{j,d}})$;
        if ($\beta_{r_{s,d}} \geq \beta_{req}$) **then** `// Check the constraint of QoT`
            if ($L^{(min)}_{r_{s,j}} > L^{(max)}_{r_{s,j}}$) **then**
                ($L^{(min)}_{r_{s,j}} \leftarrow L^{(max)}_{r_{s,j}}$);
                $NextNode \leftarrow I$;
            end
        end
    end
    $K \leftarrow NextNode$;
    `//` K `is the next node selected to transmit RREP to the source node`
    Determine SNR and load of the hop from J to K ($L_{h_{j,k}}$ and $\beta_{h_{j,k}}$);
    $L^{(max)}_{r_{d,k}} \leftarrow Max(L^{(max)}_{r_{d,j}}, L_{h_{j,k}})$;
    $\beta_{r_{d,k}} \leftarrow 1/(1/\beta_{r_{d,j}} + 1/\beta_{r_{j,k}})$;
    Store $L^{(max)}_{r_{d,k}}$ and $\beta_{r_{d,k}}$ into the RREP packet;
    Send RREP packet to node K;
end

source node (S) to node J. These informations are stored in the route cache of node J. Every time J receives a RREQ packet, J will add to its route cache a record that contains $L^{(max)}_{r_{s,j}}$ and $\beta_{r_{s,j}}$.

When a RREP packet arrives at node J, based on the information of $L^{(max)}_{r_{d,j}}$ and $\beta_{r_{d,j}}$ is stored in RREP and the records that were stored in its route cache, node J determines the maximum traffic load of the links and SNR from the source node to destination node ($L^{(max)}_{r_{s,d}}$ and $\beta_{r_{s,d}}$). Then, node J chooses next node to source node so that $L^{(max)}_{r_{s,d}}$ is minimum, concurrently, $\beta_{r_{s,d}}$ is must greater, or equal to the minimum required SNR to ensure QoT of the network. Algorithm 1 and Algorithm 2 show the pseudo-code of processing RREQ and RREP packets in QALR algorithm, respectively.

Algorithm 3: QALR algorithm at destination node (D)

Node D receives the RREQ packet from node I;
Read SNR of the route from S to I ($\beta_{r_{s,i}}$) in RREQ;
Determine SNR of the hop from I to D ($\beta_{h_{i,d}}$);
$\beta_{r_{s,d}} \leftarrow 1/(1/\beta_{r_{s,i}} + 1/\beta_{h_{i,d}})$;
if ($\beta_{r_{s,d}} \geq \beta_{req}$) **then**
    Determine traffic load of the hop from I to D ($L_{h_{i,d}}$);
    $L^{(max)}_{r_{i,d}} \leftarrow L_{h_{i,d}}$;
    Create the RREP packet;
    Store $L^{(max)}_{r_{i,d}}$ and $\beta_{h_{i,d}}$ into the RREP packet;
    Send RREP packet to source node I in order to reply to source node;
    Discard RREQ;
else
    Discard RREQ;
end

4. SIMULATION RESULTS AND DISCUSSION

We have implemented the QALR algorithm in OMNeT++ [26] to evaluate its performance. The QALR algorithm is compared with the DSR algorithm [25] in terms of the SNR, packet loss probability, and network throughput. The simulation assumptions are set as in Table 2. Figure 3 shows a snapshot of the animation interface during the simulation performance, where node N[0] is broadcasting the RREQ to all its neighbours to discovery a new route.

In Figure 4, we analyze the data packet loss probability (PLP) in the overall network. PLP is an important performance parameter of the network system. In our context, PLP is determined as the ratio of the number of blocked packets to the number of generated packets during the entire simulation time. The charts in Figure 4 have shown the difference in PLP versus traffic load in cases of using QALR and DSR algorithms. These results are simulated for the case that the number of nodes is 30, the average moving speed of each node is 20 m/s and the channel bandwidth of 40 MHz. Traffic load in Figure 4 is the metric which denotes

Table 2. Simulation parameters

Parameter	Setting	Parameter	Setting
Simulation area	1000 × 1000 m	Radio range	250 m
MAC protocol	802.11ac	Modulation type	256-QAM
Transmit power	19.5 dBm	Receiver sensitivity	-68 dBm
BER threshold	10^{-6}	Required SNR	23.5 dB
Noise model	Thermal noise	Temperature	300^0 K
Movement speed	0 - 20 m/s	Number of nodes	20 - 50
Mobility model	Random - WP	Carrier frequency	2.4 GHz
Simulation time	2400 seconds	Routing algorithms	DSR, QALR

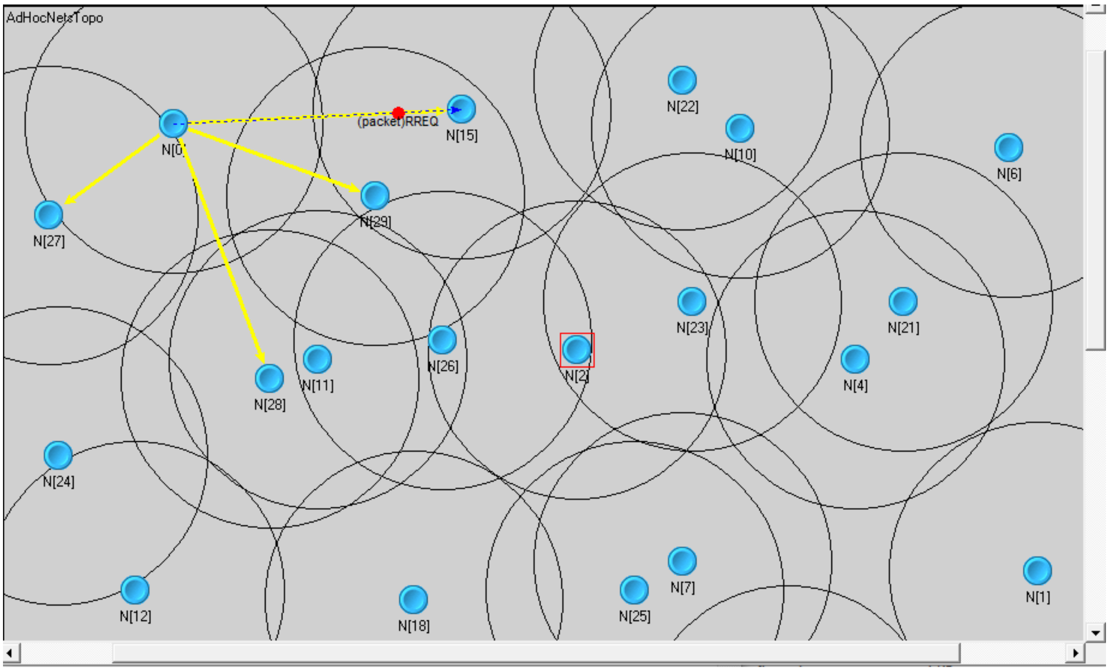

Figure 3. A topology of the MANET used for simulation

the generation traffic at the nodes. In our simulation model, the traffic load is expressed in normalized load, and it refers to the ratio of the generated average traffic intensity by each node to the capacity of one wireless link. For example, if the capacity of each wireless link is 54Mbps, and the normalized load equal to one, each node on average generates 54 Mbps, i.e. if the average data packet length is 1472 bytes, each node on average generates (54e+6)/(1472*8) = 4585.58 packets/s. The charts in Figure 4 have shown that, the QALR outperforms the DSR in terms of the PLP. For example, in the case of the normalized load of 0.6, PLPs of the DSR and QALR are 0.0263 and 0.0139, respectively. Thus, if the QALR algorithm is used, PLP in the network reduces to 47.1%. For other cases, PLP of QALR algorithm decreases by an average of 64.15% compared to that of DSR algorithm. In

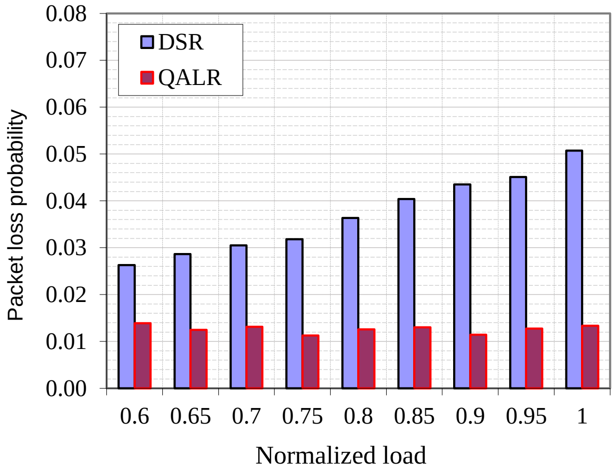

Figure 4. The performance of DSR and QALR algorithms under packet loss probability versus normalized load

particular, the higher the normalized load, the more efficient QALR algorithm is about PLP. This is because QALR algorithm selects the route so that the load distribution is balanced for links in the entire network. Therefore, in the case of heavy traffic loads, the QALR algorithm minimizes bottlenecks at nodes and links, resulting in a reduction in PLP of the entire network.

In addition to dependence on the normalized load, PLP also depends on the movement speed of the nodes. The simulation results in Figure 5 have shown that the higher the moving speed of the nodes, the higher the PLP. However, the QARL algorithm always yields a smaller PLP than the DSR algorithm. Considering the case of the network size of 40

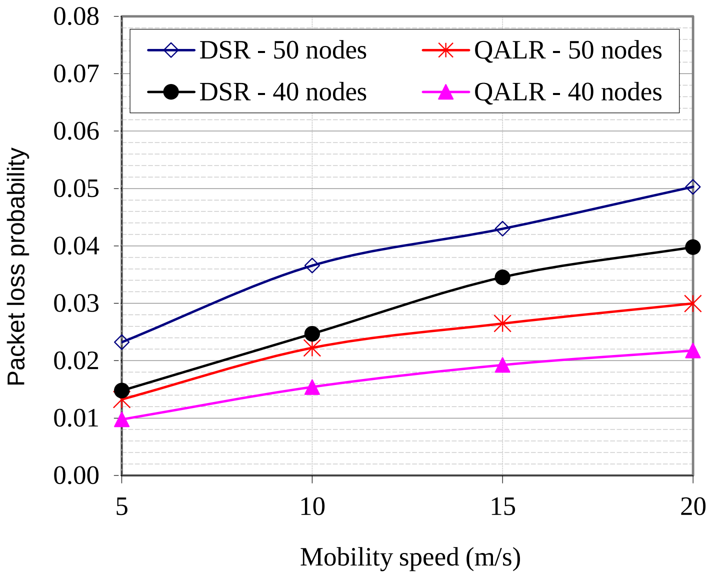

Figure 5. The performance of DSR and QALR algorithms under packet loss probability versus mobility speed

nodes, the PLP of QALR algorithm decreases by an average of 40.28% compared to the DSR algorithm. This value is 40.23% in case of the network size of 50 nodes. The curves in Figures 5 also show the faster the mobility speed, the more effective QALR algorithm is, the larger the difference between DSR and QALR algorithm.

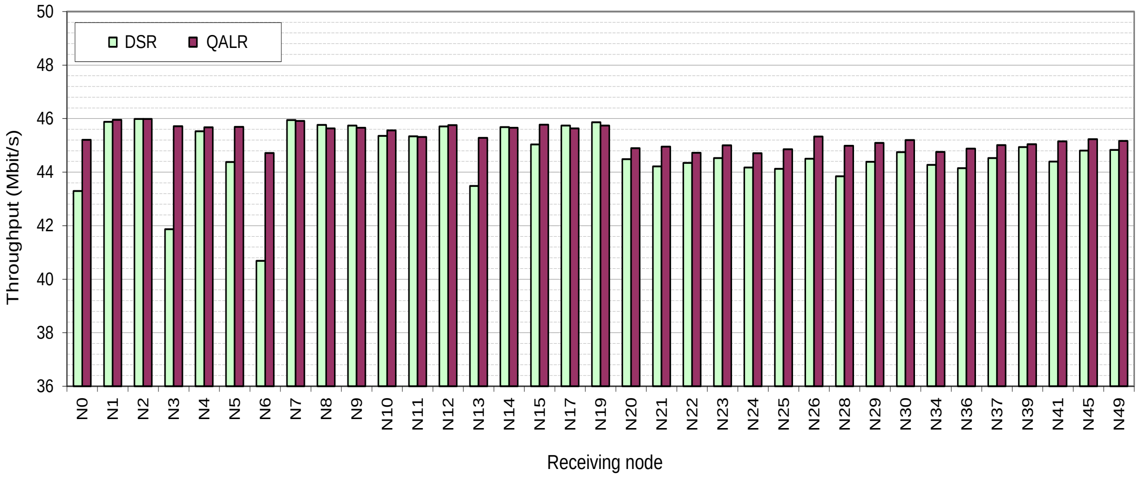

Figure 6. The performance of DSR and QALR algorithms under receive throughput by nodes

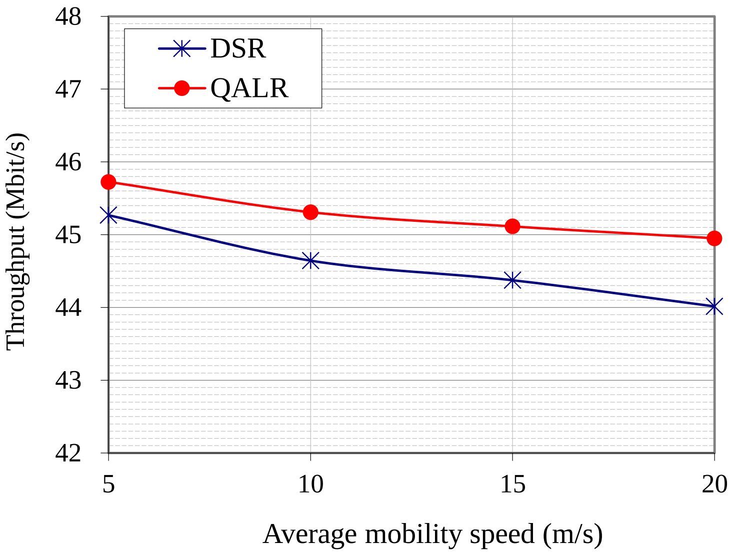

Figure 7. The performance of DSR and QALR algorithms under the average throughput of all receiving nodes versus mobility speed

For throughput, the QALR algorithm also performs more efficiently than the DSR algorithm. This is more clearly visible from Figure 6, where we plot the received throughput chart at the nodes for QALR and DSR algorithms. We can observe the throughput of QALR algorithm is always higher than the that of the DSR algorithm. For example, the throughput of node N0 in cases of QALR and DSR algorithms are 43.29 and 45.21 Mbit/s, respectively.

Thus throughput increases by 1.91 Mbit/s in case of QALR algorithm. The average throughput of all receiving nodes is shown in Figure 7. These results are simulated for the case of the network size of 50 nodes and the normalized load of 0.6. We can observe the throughput of both DSR and QALR algorithms decrease according to increasing of the mobility speed of the nodes. However, the throughput of QARL algorithm is always higher than that of the DSR algorithm. For the cases of the average mobility speed of 5, 10, 15 and 20 m/s, the increased value of the throughput are 4.6, 6.7, 7.4 and 9.4 Mbit/s, respectively.

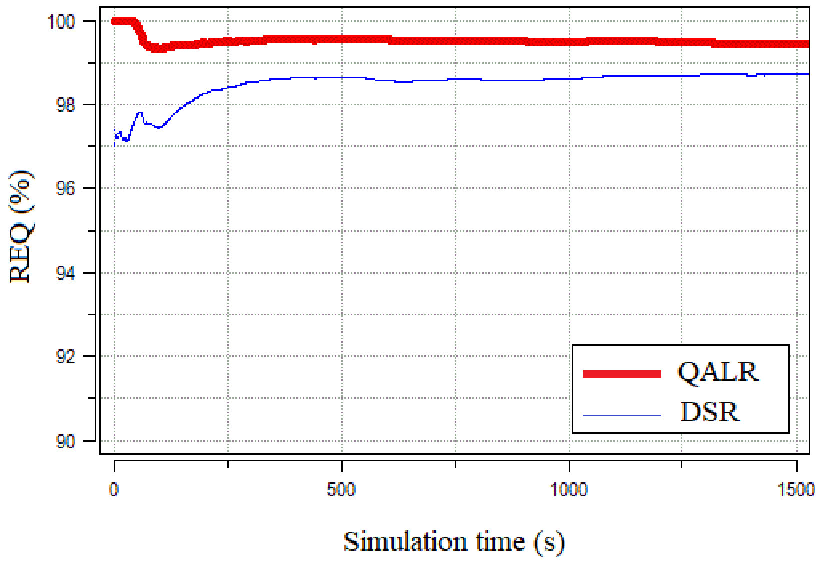

Figure 8. The performance of DSR and QALR algorithms under the ratio of routes ensuring QoT

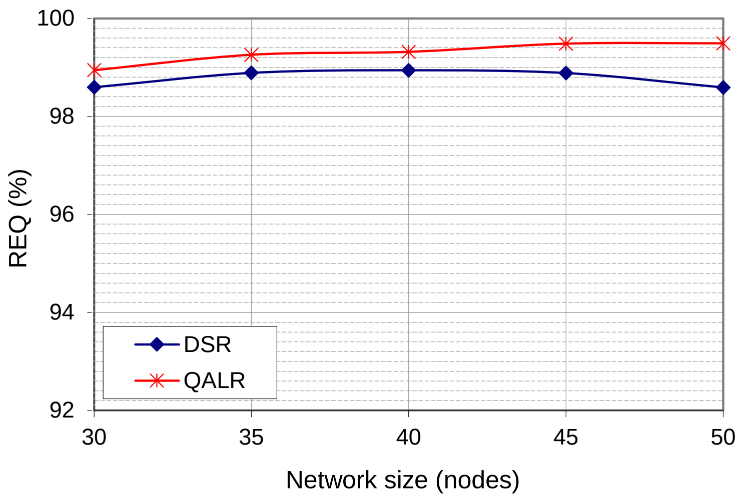

Figure 9. The performance of DSR and QALR algorithms under the ratio of routes ensuring QoT versus the network size

The next performance parameter that is analyzed in our simulation is the SNR of the data transmission channels in the network. In Figure 8, we compare REQ (Ratio of Routes

Ensuring QoT) in cases of using DSR and QALR algorithms. In our context, REQ is defined as follows

$$REQ = \frac{N_E}{N_A}, \tag{2}$$

where N_E is the number of routes ensuring QoT, i.e. the routes that its SNR is greater than required SNR. N_A is the number of routes in the network. The curves in Figure 8 have shown the QALR algorithm outperforms the DSR algorithm in term of the REQ. The average REQ of the DSR and QALR are 98.59% and 99.49%, respectively. Thus, the average REQ increases by 0.9% if comparing with DSR algorithm. In the case of the variable network size, The average REQs of both DSR and QALR are shown in Figure 9. When the number of nodes changes from 30 to 50 nodes, REQ of the DSR and QALR are from 98.59% to 98.88% and from 98.94% to 99.4%, respectively. Thus, QALR algorithm always yields REQ higher than DSR algorithm. The reason for this is that QALR algorithm has considered the QoT constraint condition during route discovery, so the found routes always satisfy the QoT constraint condition.

From the simulation results presented above, we can conclude the proposed QALR algorithm has found the load balancing routes, and these routes concurrently satisfy the QoT constraint conditions. As a result, network performance is significantly improved in terms of QoT, packet loss probability, and network throughput. In particular, QALR algorithm is highly efficient in the case of the heavy traffic load because the load balancing technique has been applied in this algorithm.

5. CONCLUSIONS

In mobile ad hoc networks, the load balancing routing is one of the most effective solutions to improve its performance in terms of the packet loss probability and network throughput. The main reason for this is that the load traffic is distributed evenly for all links in the network. However, in the case of the MANET using the relay type of amplify-and-forward (AF) based cooperative communications, the load balancing routing can reduce the QoT since the routes can pass through multiple hops, and the power of the noise signal can amplify at intermediate nodes. In this paper, we proposed a routing algorithm for MANET using AF that takes into account both load balancing and QoT. Our proposed algorithm is improved from route recovery algorithm of DSR protocol, called QALR. The performance of QALR algorithm is investigated by the simulation method using OMNeT++. The simulation results have shown that the proposed algorithm can improve the network performance in terms of QoT, packet loss probability, and throughput compared with DSR algorithm.

In the future, we continue to investigate the QoT of MANET using AF in cases of using the other routing protocols such as Ad hoc On-Demand Distance Vector (AODV), Destination-Sequenced Distance-Vector Routing (DSDV).

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